

ABSTRACT

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Orbit Determination of HITEN for Insertion into Lunar Orbit

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On Feb. 15, 1992 the HITEN spacecraft was inserted into orbit about the Moon. HITEN was launched on 24 Jan, 1990 by Japan's Institute for Space and Astronautical Science (ISAS) and traversed the Earth's geotail region, survived two aerobraking passes in the Earth's atmosphere (March 1991), and visited the regions near the Earth-Moon L_4, L_5 Lagrangian libration points prior to its capture into lunar orbit. It remained in a 3.5 day period orbit at an inclination of 31 degrees until impact 28 Mar. 1993 on the lunar backside. This return to the Moon marked the first resumption of extended communication with any spacecraft or instruments in orbit about or on our closest celestial neighbor since the Apollo-17 mission in Dec. 1972 and the deactivation of the ALSEP instrumentation on the Moon in the late 1970's.

NASA/ JPL Deep Space Network (DSN) tracking support was provided during several phases of the mission. This paper includes brief descriptions of the entire mission and summarizes JPL's role during various phases. The first use of a sojourn to the Earth/Moon weak stability boundary for achievement of a low energy expenditure transfer from geocentric orbit to selenocentric orbit is also reviewed. Primary focus of this paper is on the JPL Multi mission Navigation 'learn (MMNAV) orbit determination effort in providing accurate HITEN orbit determination (OD) in preparation for the successful insertion into lunar orbit. Details of this support and a summary of results are provided.

HITEN and its small accompanying subsatellite HAGAROMO were launched together as MUSKS-A. One of HITEN's primary objectives was to demonstrate attitude and orbit control technology of a spinning spacecraft for control of the line of apsides as a precursor to the current GEOTAIL mission. This control made regular use of gravity assist lunar swingbys. Accurate targeting of lunar swingbys early in the mission was important with respect to the total Delta-V budget for the entire mission. The DSN was requested to provide tracking and orbit determination support during the launch and early orbit phase of the mission as well as during other phases of

the mission where accurate 01) was required. High accuracy was more readily achievable with tracking data from a worldwide network rather than from the Japanese domestic stations which offered limited viewing geometry relative to the DSN.

The JPL Multimission Navigation Team provided post injection OD which assisted the ISAS recovery from a non nominal injection. Maneuvers based on JPI, orbit solutions were performed which pumped the orbit out from the actual 6 day period initial orbit with an apogee at approximately 3×10^5 km to the desired 12 day period orbit with an apogee beyond the lunar orbit. At this point the nominal mission was resumed.

The mission scenario began with the release of HAGAROMO at the first lunar swingby and firing of its onboard thruster for injection into lunar orbit. HAGAROMO's exact fate is unknown as the subsatellite suffered a loss of its electrical system prior to separation. The intended lunar beacon is assumed to be a mute voyager in possible eternal orbit about the Moon.

HITEN continued its journey on a geocentric trajectory including a series of lunar swingbys in conjunction with propulsive trajectory change maneuvers (TCMs) which maintained the distant apogees in the anti-Sun direction, i.e. the geotail direction. This phase of the mission continued through 1990. In March 1991, HITEN was targeted for 2 aerobraking passes through the Earth's atmosphere. The first was at an altitude of 125km and the second at 120km.

After surviving these two brief escapades, HITEN spent the next six months in distant Earth orbit and passed in the vicinity of the two stable Earth-Moon libration points L_4 and L_5 .

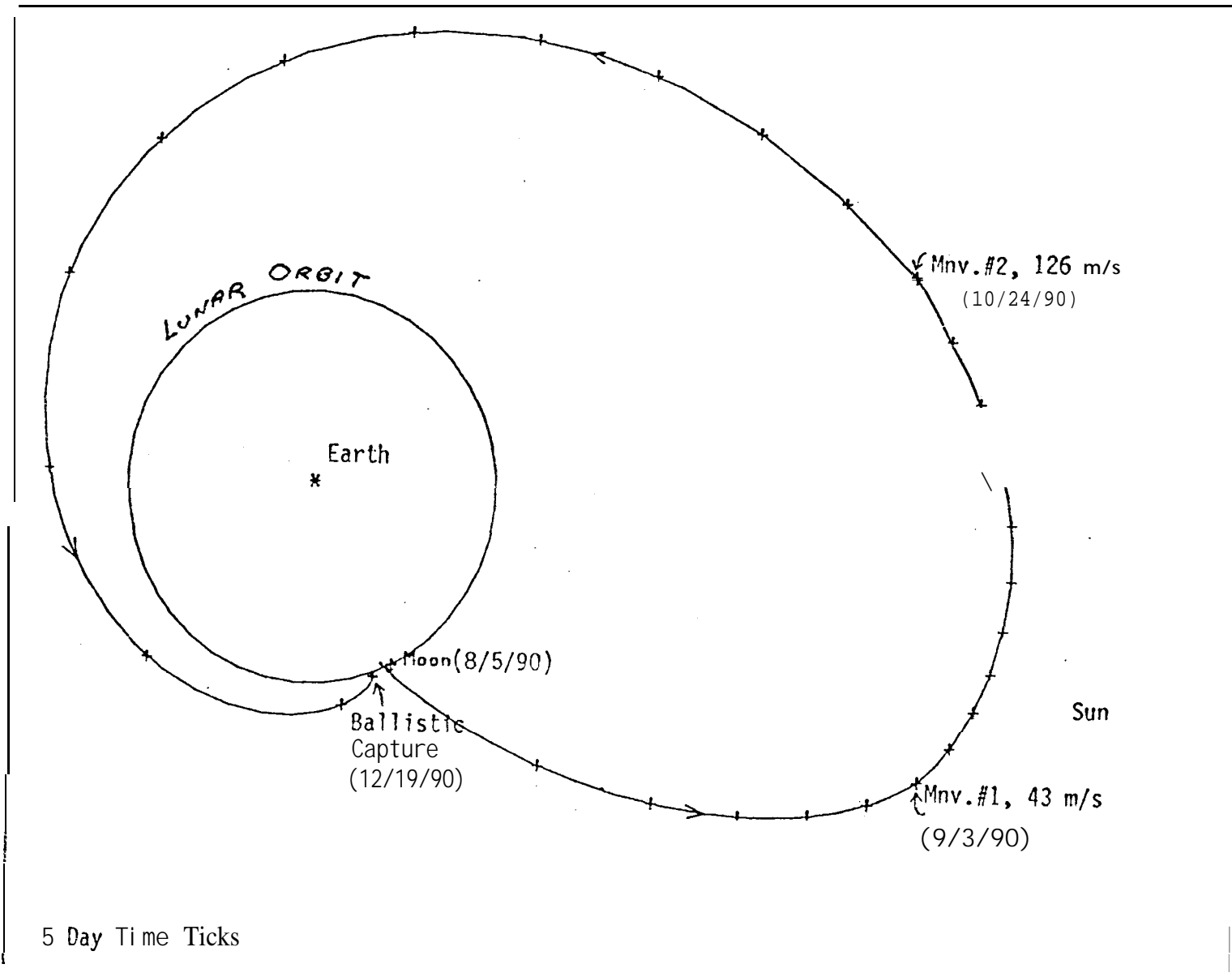
During the time of HITEN's meandering in cis-lunar space, JPL orbit analysts were studying the concept of transfers of spacecraft orbits between celestial bodies utilizing small propulsive maneuvers in the vicinity of the "weak stability boundary" (WSB) associated with the two central bodies. JPL was able to generate an integrated trajectory based on a current HITEN state vector which indicated the possible use of this concept for the transfer of the spacecraft from geocentric orbit to selenocentric orbit culminating with a ballistic capture at the Moon (Fig. 1). These results were communicated to ISAS and the mission profile was subsequently modified to incorporate this concept into the HITEN mission profile. The same technique is being utilized in the baseline design of the ISAS LUNAR-A mission scheduled for launch in 1997.

Late in 1991, the orbit of HITEN took the spacecraft out to a geocentric distance of approximately 1.4×10^6 km at a point on the Earth-Moon WSB. From this point the spacecraft plummeted toward a lunar swingby which was still hyperbolic, but required only a modest Delta-V for capture into a highly elliptic lunar orbit. Accurate orbit determination was desired to assure proper design of the final capture TCM at perilune. JPL, MMNAV and the DSN supported this critical phase of the mission.

DSN tracking was limited to Madrid and Goldstone due to the constraint to avoid conflicts with the LSAS station views. Canberra and LSAS Usuda/Uchinoura site view periods were nearly concurrent. Covariance analysis was performed assuming the availability of brief three hour duration 2-way S-band Doppler and range tracking passes once a day from both Madrid and Goldstone. The data arc extended from 3 days prior to perilune until 1.5 days prior to perilune. Results indicated perilune B-Plane (Fig. 2) position accuracy prediction on the order of 3km could be provided in time for implementation of any final targeting trim maneuver (if required) during the final pre-perilune view period from the LSAS tracking site. The final JPL MMNAV orbit solution delivered to LSAS prior to perilune was based on data from the 2 DSN sites spanning 32 hours on 12-14 Feb. 1992. It yielded a predicted B-Plane position uncertainty of 3.3km (Fig. 3).

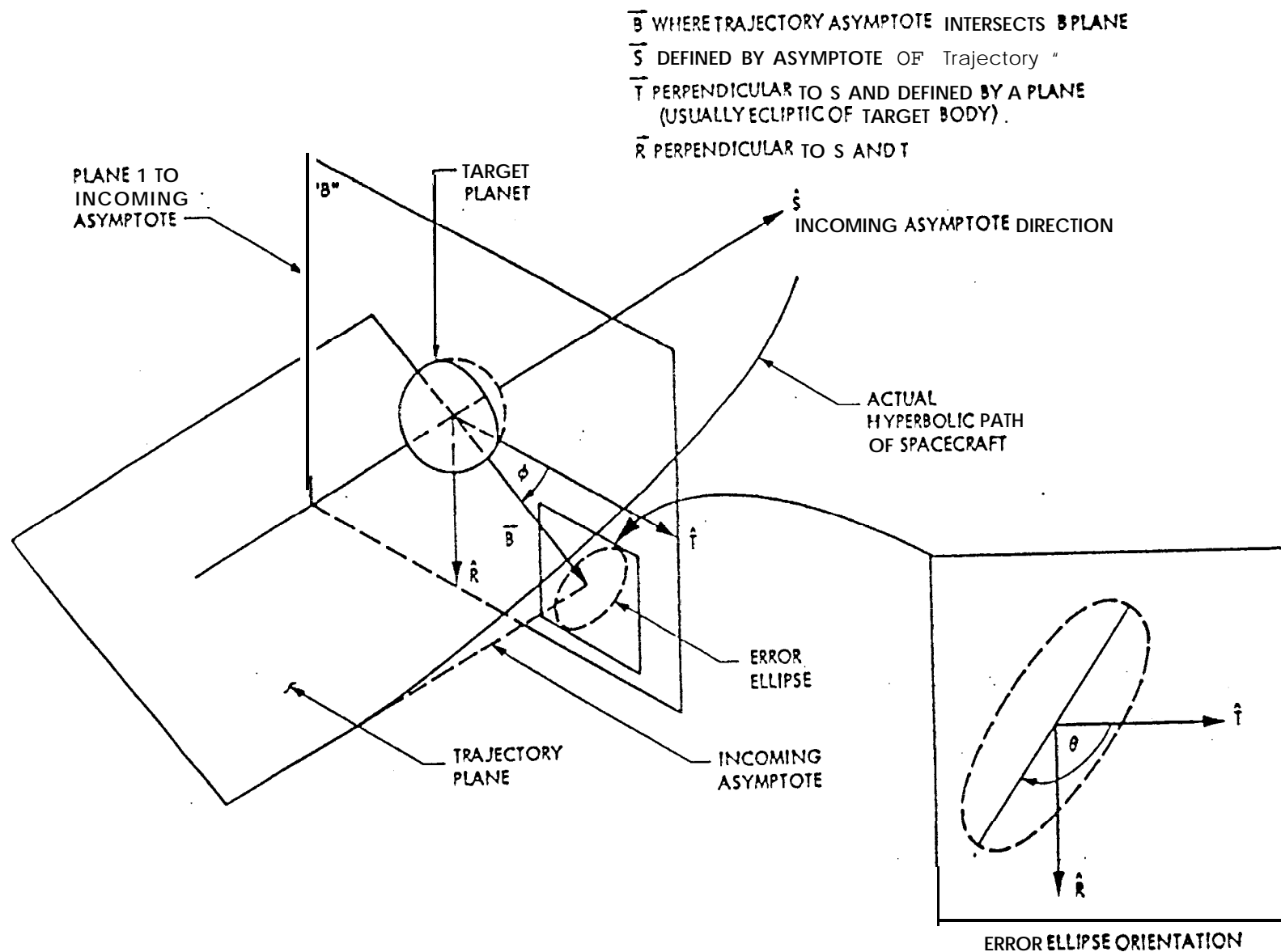
HITEN was successfully captured into lunar orbit at 13:18 UTC on 15 February 1992. The orbit had a period of approximately 3.5 days with initial perilune altitude of approximately 420 km. Third body perturbations had a significant effect on the orbit. On 28 March 1993, after 13 months of selenocentric travel, HITEN impacted the backside of the Moon.

MUSES LUNAR CAPTURE ORBIT



Ecliptic Plane (XY) Projection (EM050), FAST Integrated
Capture at 100 km Altitude

FIG. 1



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Fig. 2 B-plane definition.

HITEN ORBIT SOLUTION (2 RAD & 2 GDS PASSES)

